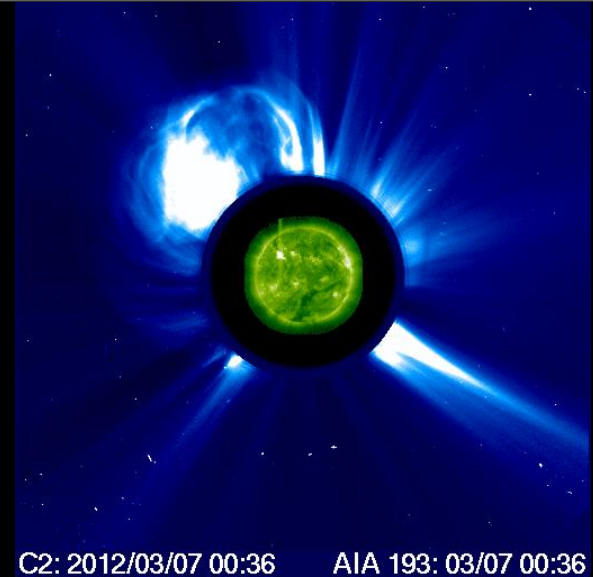
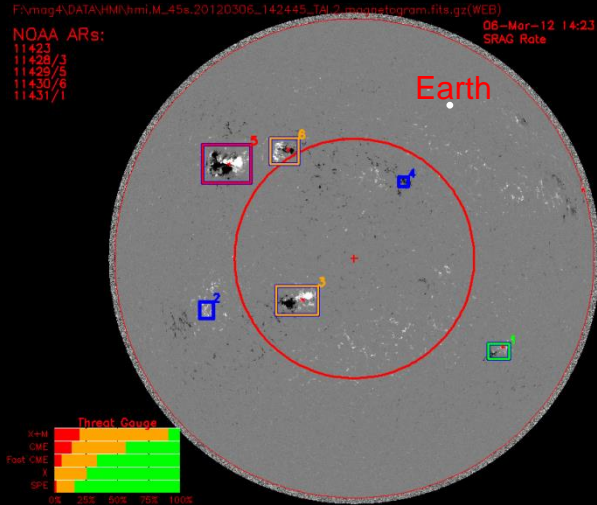


NOAA ARs: 11423
11426/3
11429/5
11430/6
11431/1

06-Mar-12 14:23
SRAG Rate

Earth



David Falconer
September 20, 2016

www.nasa.gov

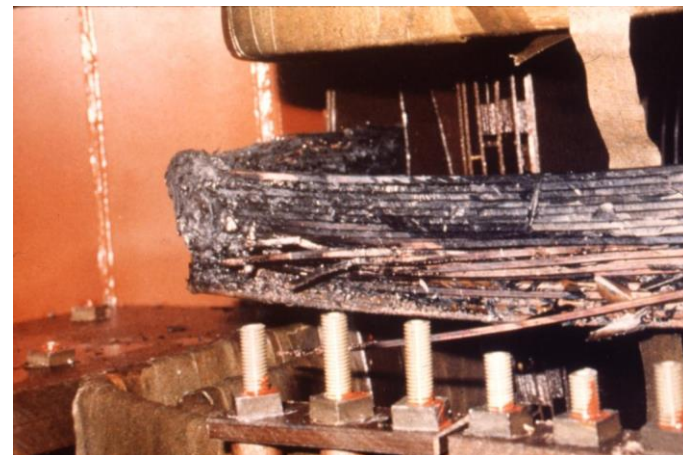
Catastrophic Damage: A Modern Carrington Level Event

Lesser Event

Major Damage

“This image shows heating related damage to the current carrying windings of the transformer. To provide cooling for normal operations, the coils are immersed in an oil-bath. As you can see, an oil-bath does not cool well enough to protect against the GIC.”

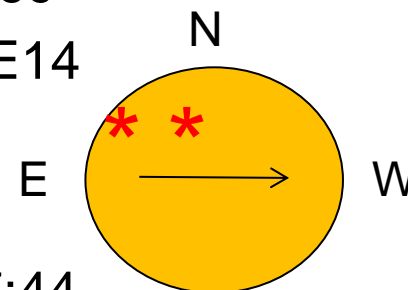
Damaged Power Station Transformer



March 1989 Quebec Blackout

On March 13, 1989 the entire province of Quebec, Canada suffered an electrical power blackout.

- AR 5395 produced on March 6, 14UT a X15 flare N35E69
- March 10 18UT a X4.5 flare N35E14
- Geomagnetic event starts on March 12.
- Reaches a DST -589 on March 13 1UT
 - largest DST magnitude in last 50 years. March 13, 7:44 UT Quebec Blackout



“On the evening of Monday, March 12 the vast cloud of solar plasma (a gas of electrically charged particles) finally struck Earth's magnetic field. The violence of this 'geomagnetic storm' caused spectacular '**northern lights**' that **could be seen as far south as Florida and Cuba**. The magnetic disturbance was incredibly intense. It actually created electrical currents in the ground beneath much of North America. Just after 2:44 a.m. on March 13, the currents found a weakness in the electrical power grid of Quebec. In less than 2 minutes, the entire Quebec power grid lost power.” ***Dr. Sten Odenwald***

Drivers of Space Weather

Flare

Coronal Mass Ejection (CME)

SPE

ELECTROMAGNETIC RADIATION
(IMMEDIATE: TIME 8 MIN)

X-EUV ULTRA-VIOLET VISIBLE LIGHT RADIO WAVES

SIMULTANEOUS EFFECTS

INCREASED D-LAYER IONIZATION

GEOMAGNETIC DISTURBANCE

ANOMALOUS RADIO PROPAGATION

OUTBURST OF RADIO NOISE

RADIO INTERFERENCE

HIGH ENERGY PARTICLES
(DELAYED < HOUR)

ATOMIC NUCLEI

ENHANCED SOLAR WIND
(DELAYED 1-3 Days)

IONS AND ELECTRONS

DELAYED EFFECTS

ENHANCED ENERGETIC PARTICLES

MANNED FLIGHT RADIATION HAZARD(I)

SPACECRAFT RADIATION HAZARD (C³)

Polar Flights

IONIZATION

ANOMALOUS RADIO PROPAGATION

RADAR CLUTTER

GEOMAGNETIC STORM

IONOSPHERIC STORM

INDUCED CURRENTS

RADIO EFFECTS

SATELLITE DRAG

AURORA

Pipeline Corrosion

Solar Proton Event (SPE)

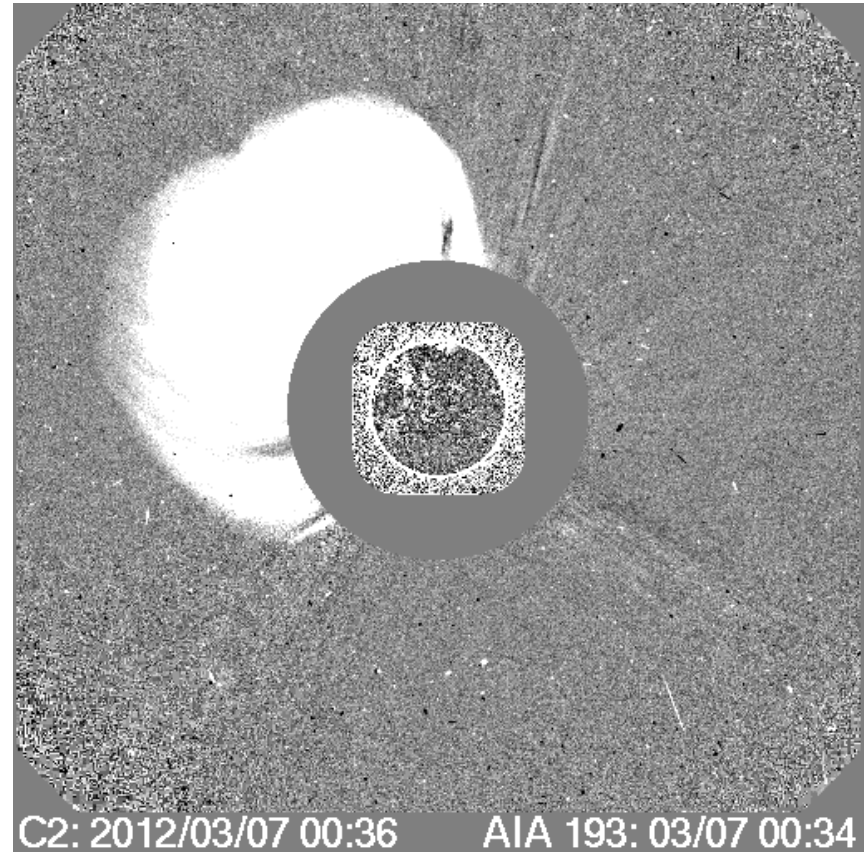
Space Weather

Geomagnetic Storm

- Powerful CME
- Earthward Directed
- Strong Coupling with Earth Magnetosphere

Threat to Local Power Grid

- Magnetic Latitude (high latitude most at risk)
- Magnetic Longitude
- Local Geology
- Power Grid

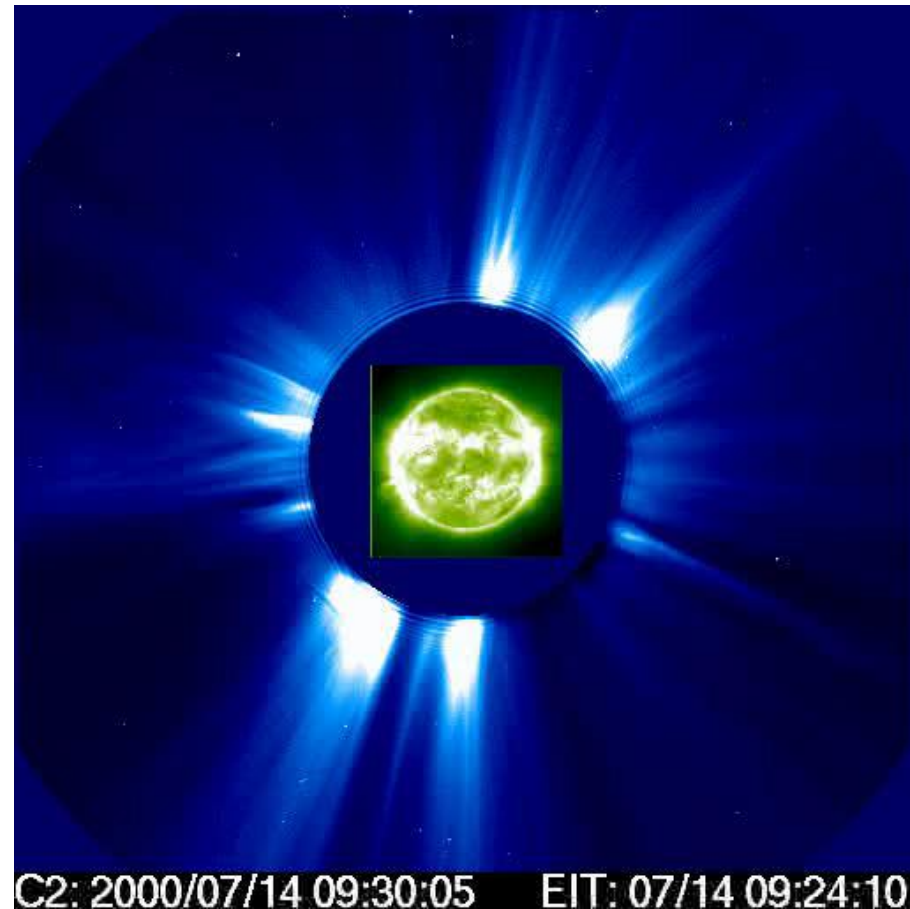
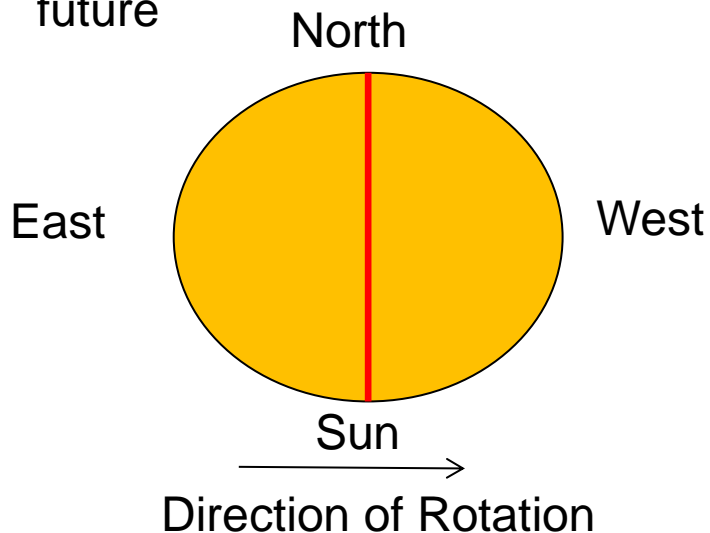


“Perfect” Storm

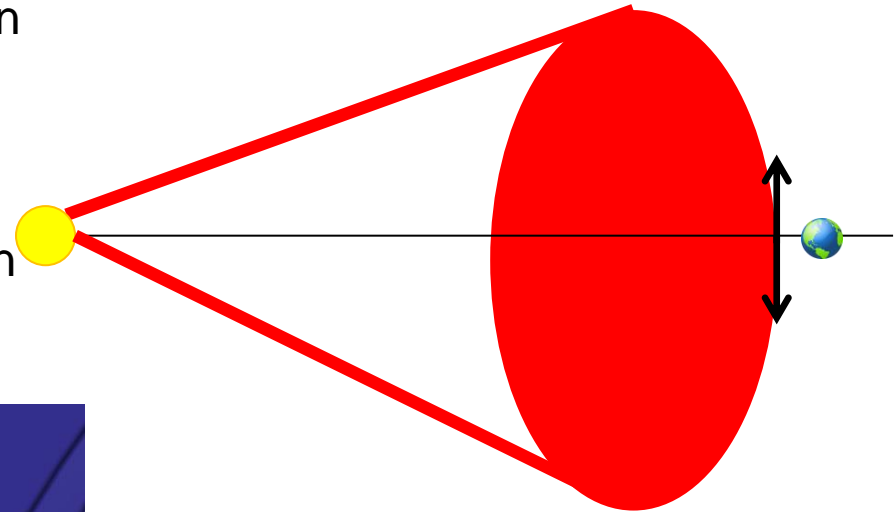
CMEs that are not directed toward Earth cannot cause geomagnetic storms on Earth

Active regions near disk center are dangerous

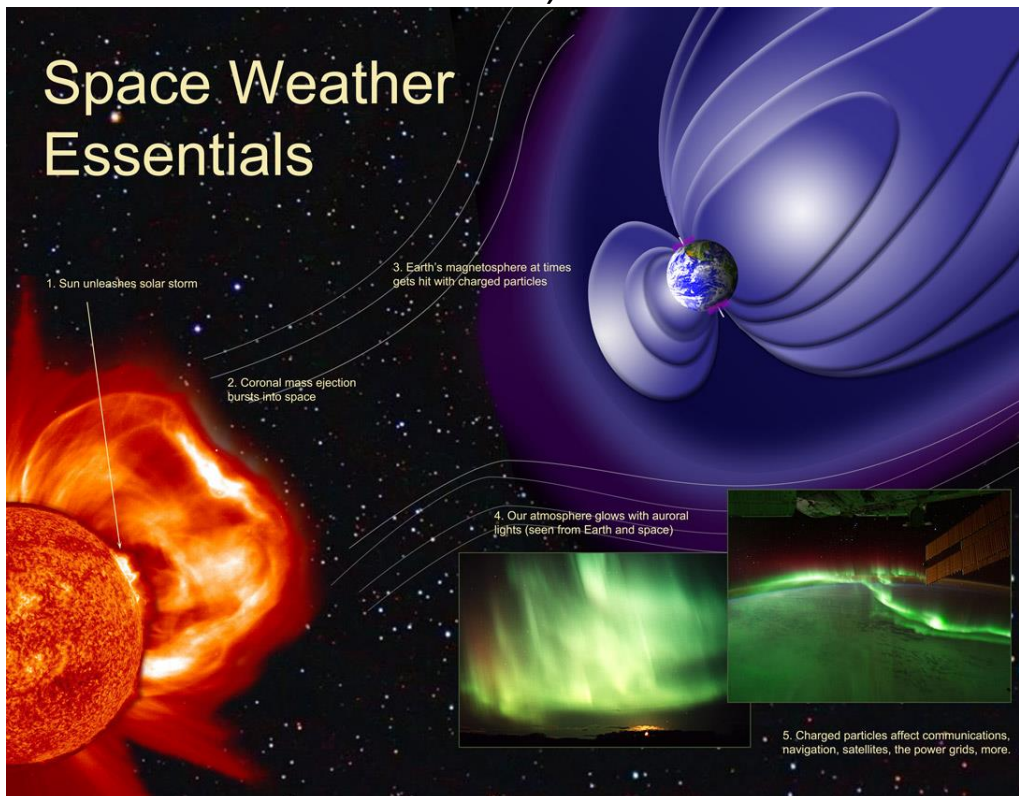
Active regions to the left of disk center (East) will be a threat in future



- Magnetic coupling is the strongest when the vertical component the CME's magnetic field is directed southward
- The direction is only known as CME passes ACE at L1 position, where it can be measured (1% of the distance from the Sun to the Earth)

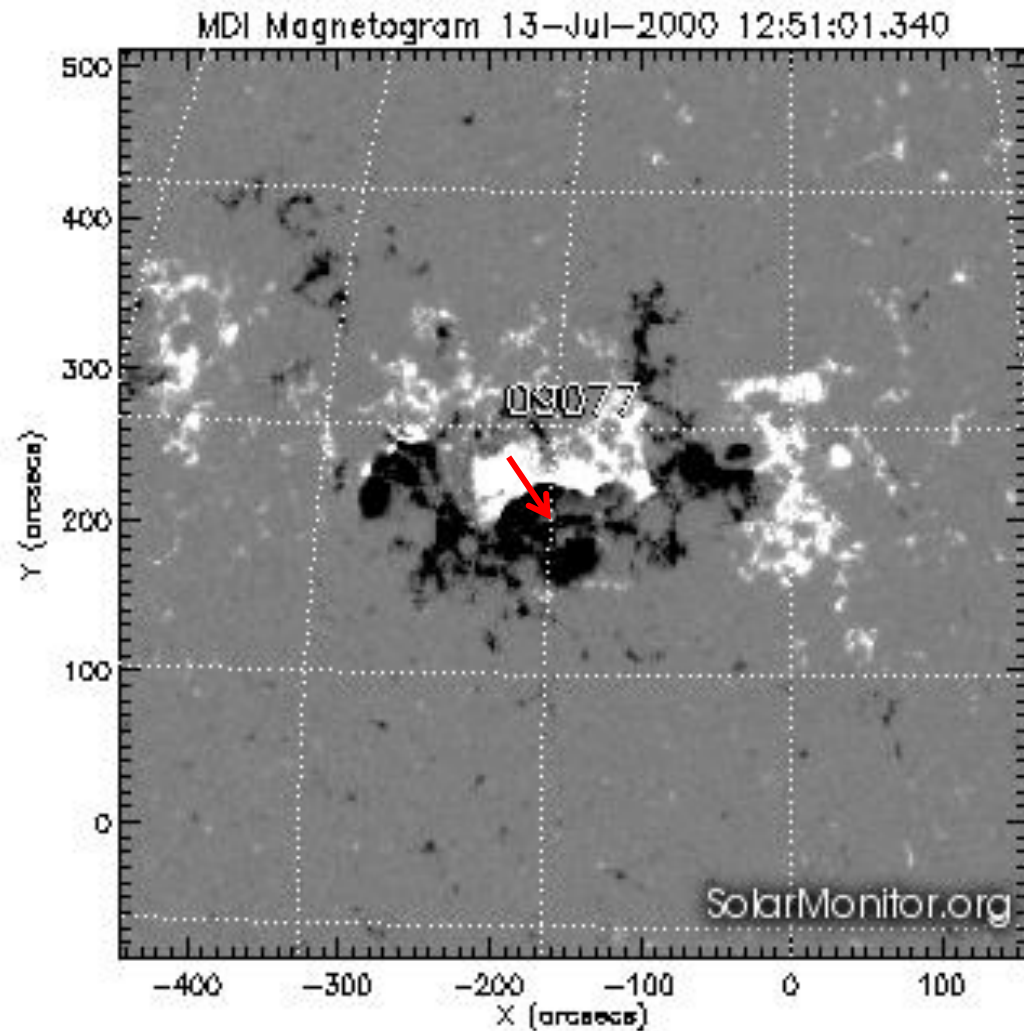


Earth, Sun not to Scale

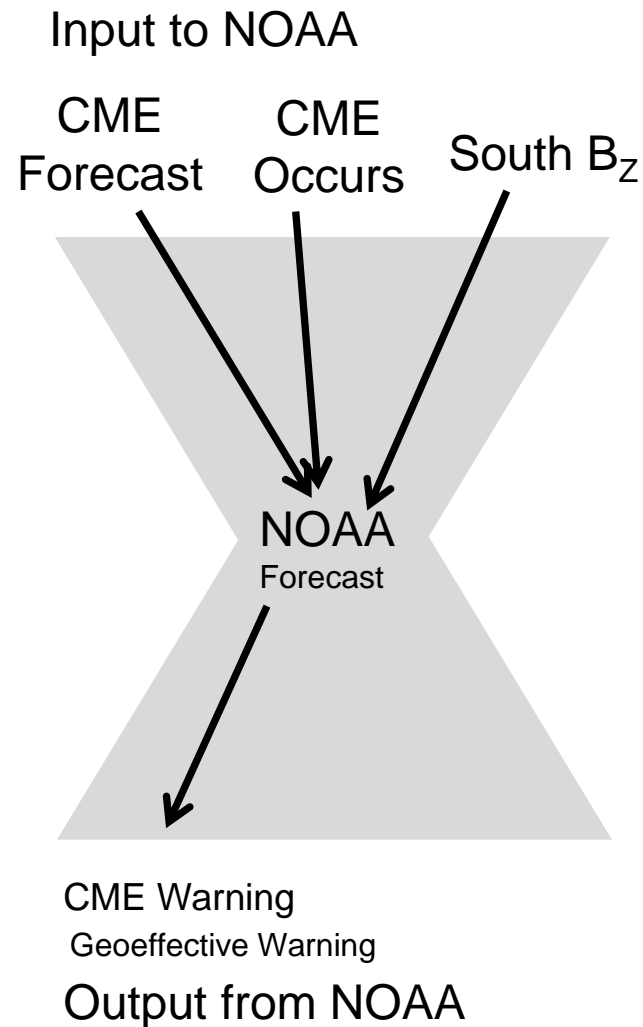


Not to Scale
Credit: NASA

- There is a loose correlation between the overarching magnetic field, and the leading edge magnetic field
- Work is being done to improve the forecasting
- Gives more warning for severe geomagnetic storm
- Not yet ready for Research to Operations (R2O), much less Operations



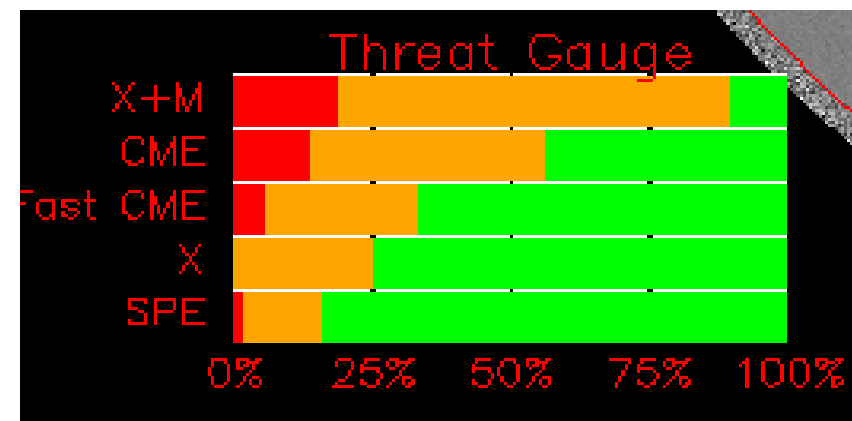
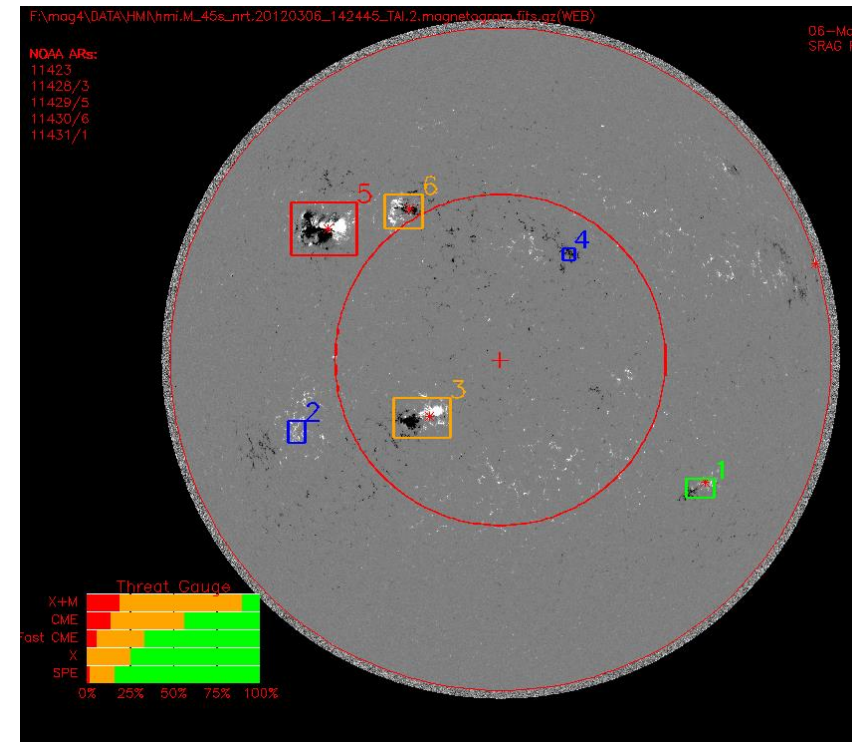
- Watch
 - A threatening active region is rotating toward or is near disk center
 - In most cases, except for a rapidly emerging active region, this gives several days of notice
- Warning
 - An active region near disk center has produced a large flare and a fast CME
 - ~24-48 hours of notice, the faster more dangerous ones, less time
- Good magnetic coupling
 - ACE is at 0.99 AU (Earth at 1 AU), warnings of order of tens of minutes



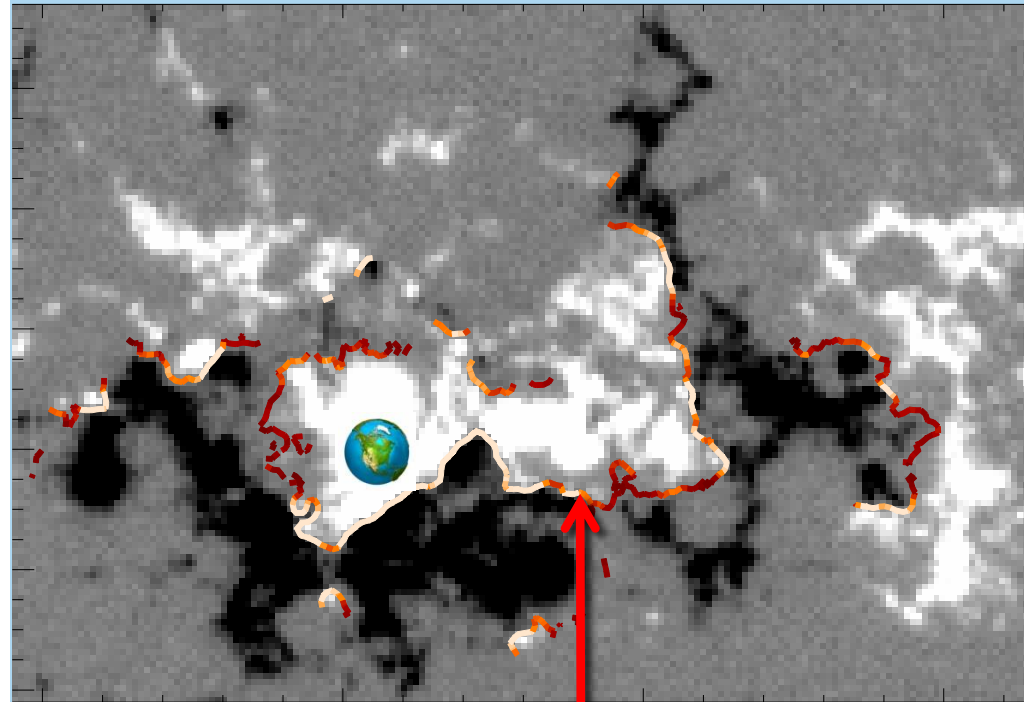
NOAA/SWPC does the day to day forecasting
<http://www.swpc.noaa.gov/>

MAG4 CME Forecast of Fast CME

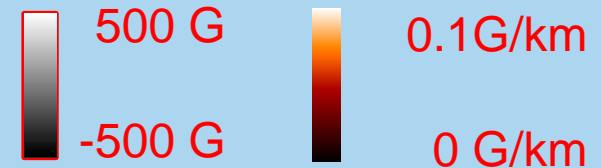
- Coronal Mass Ejections (**CMEs**), like earthquakes are very difficult to predict
- Correct answer most of the time is No! (Useless forecast)
- Historical records can provide empirical base forecasts
- MAG4 (Magnetogram Forecast) uses empirical data to predict the event rate of dangerous solar activity
- It does this automatically 24/7, making new forecasts every 96 minutes
- It forecasts **major flares**, **CMEs**, and Solar Proton Events (**SPEs**)



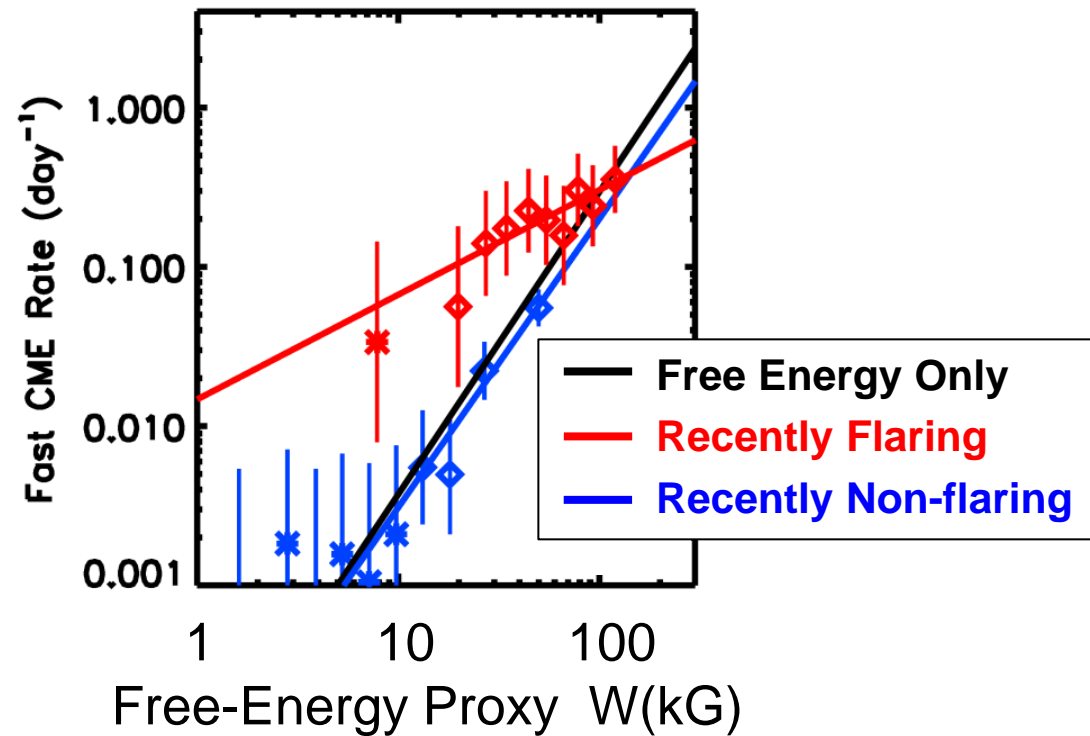
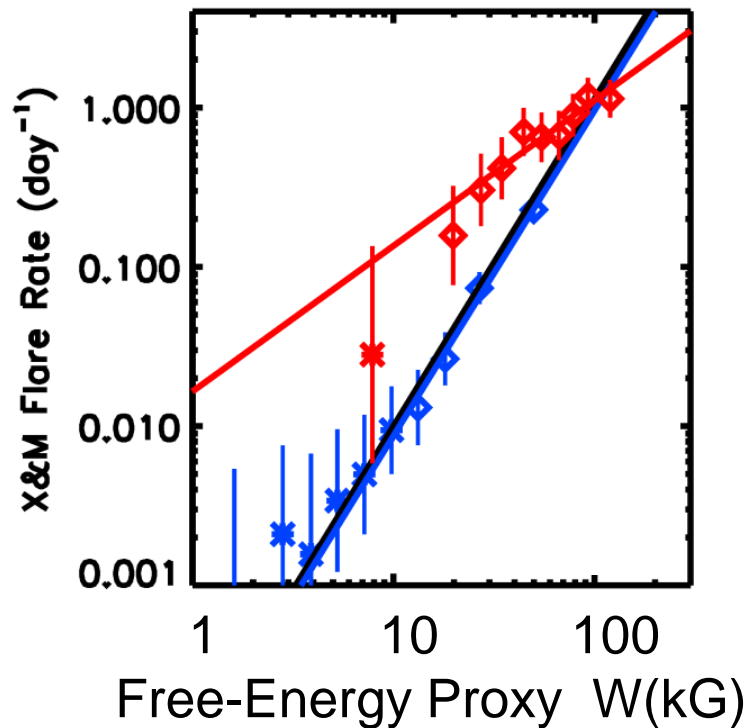
- Flares and CMEs are powered by magnetic energy stored in the chromosphere and corona
- Direct measurements of coronal magnetic energy are inaccurate
- When the magnetic field is stressed, the more energy is stored and available for “explosive release”; more energy is stored, greater the chance of a major flare
- MAG4 uses a proxy to quantify the free energy stored in an active region
- Event rates are correlated with the magnitude of the free-magnetic-energy proxies



Neutral Line, color coded for gradient

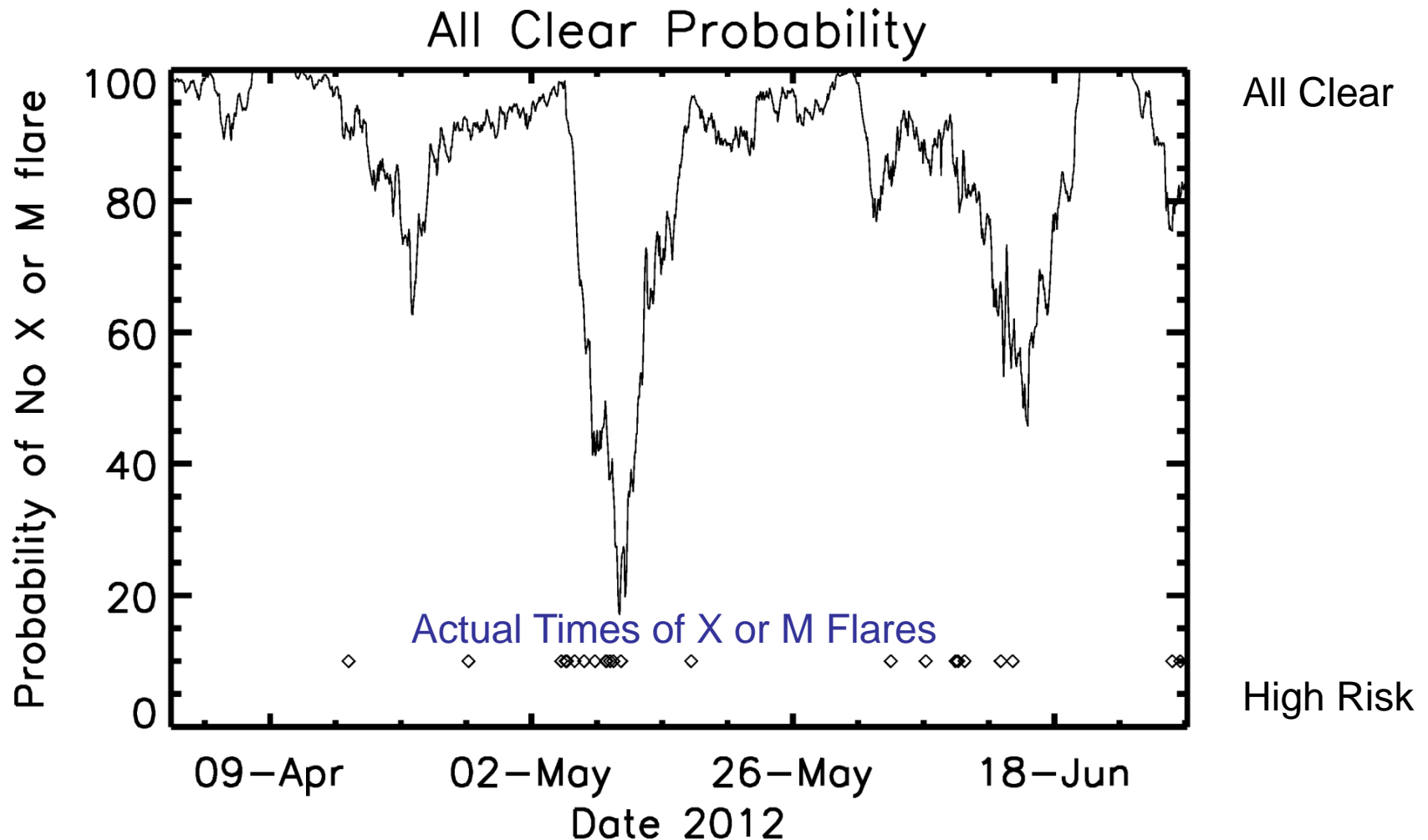


Earth magnetic field 1 G



Active regions that have recently produced an X- or M-Class flare are more likely to produce flares in the near future

Actual operational data from JSC/SRAG



June 26, 2013

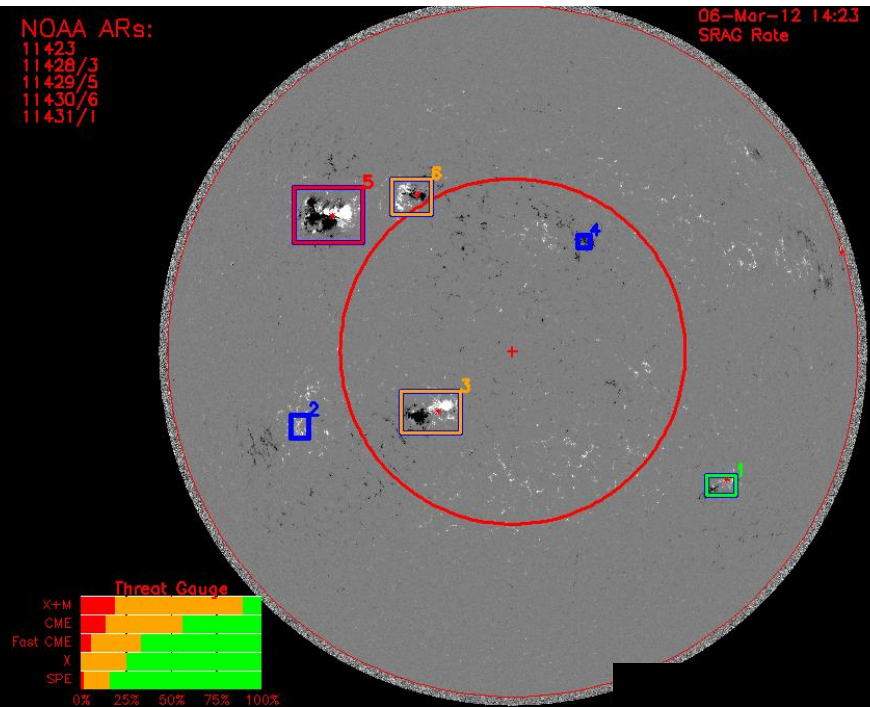
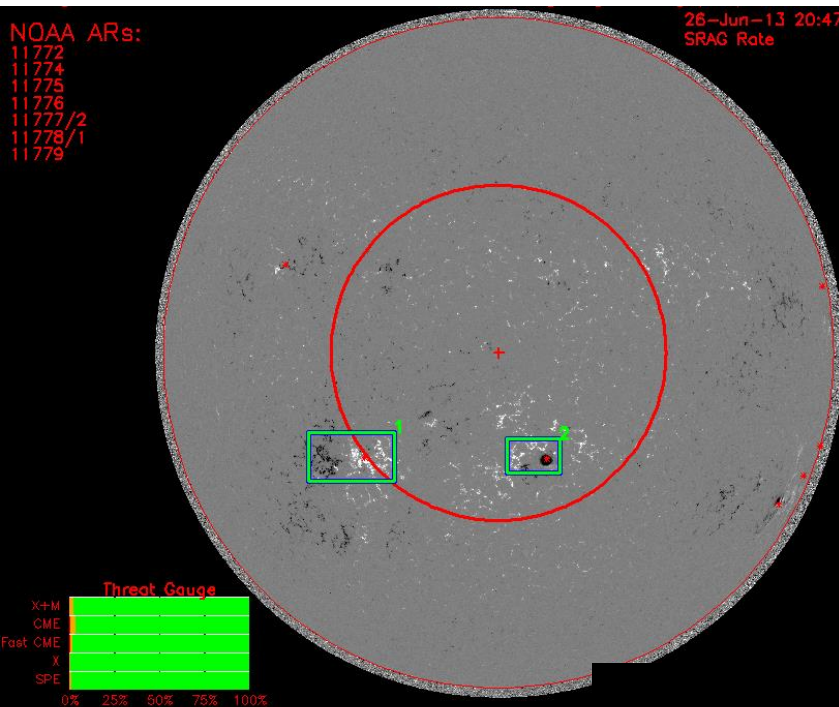
C1, C1.5 flares

March 7, 2012

X5.4, X1.3, C1.6

CME 2684, 1825 km/sec,

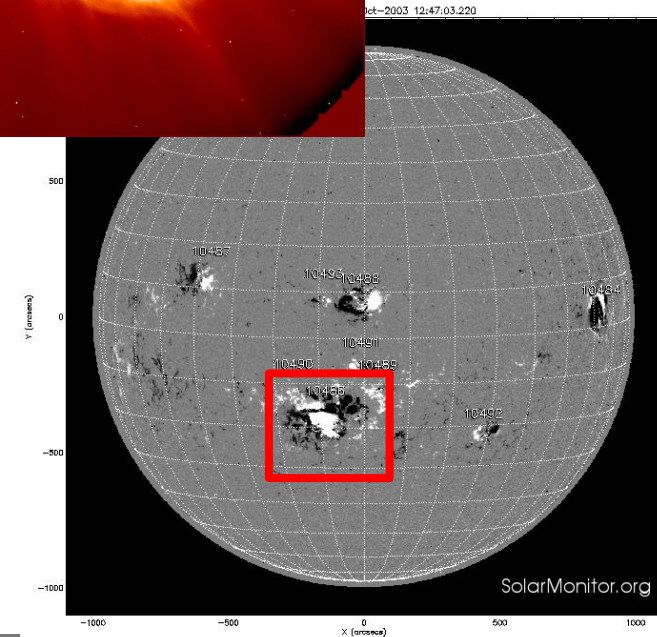
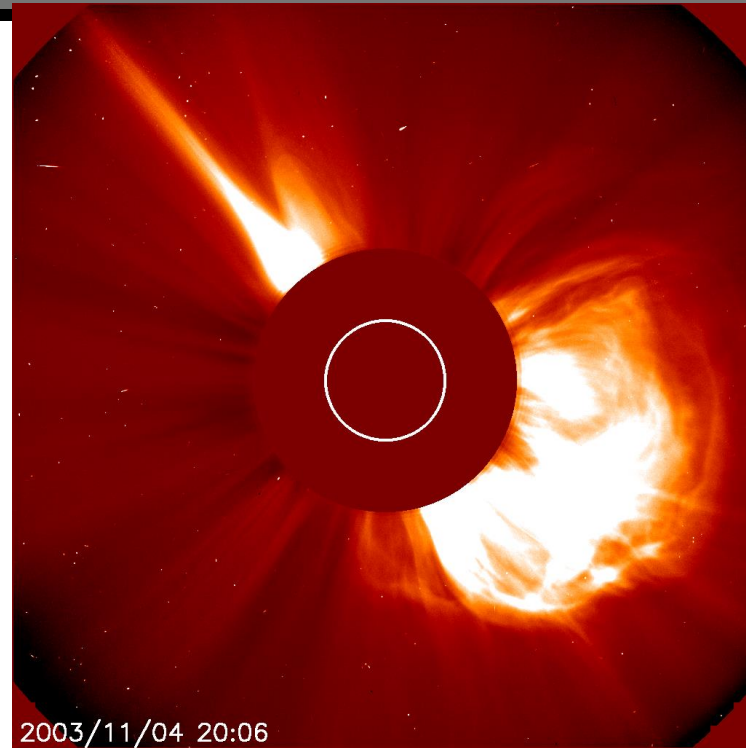
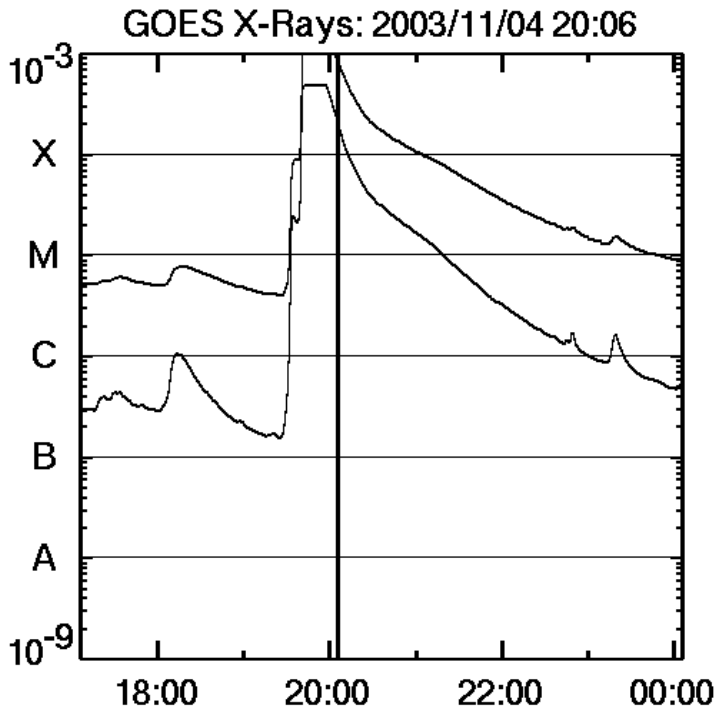
Solar Energetic Proton Event reaches
6530 particle flux unit >10MeV



Conclusions

Forecasting CMEs is the first step to forecasting dangerous Geomagnetic Storms and possible threat to Alabama's Power Grid

- Geomagnetic Storm Watch: Dangerous active region is near disk center or approaching
- Warning: Fast, Earth-Directed CME has occurred, 1-4 day arrival time, the faster ones are the most dangerous
- ACE at L1, has determined that the CME has a southward B_z
- Need to know what level of event, timing and other factors will affect Alabama's Power grid (instead of New York's)
- Need a plan to minimize long-term damage
 - Safe Mode
 - Similar to tornado impact plan



- What if this happened 7 days earlier

Definitions

	Actual Yes	Actual No
Predict Yes	YY	YN
Predict No	NY	NN

Metric Equations

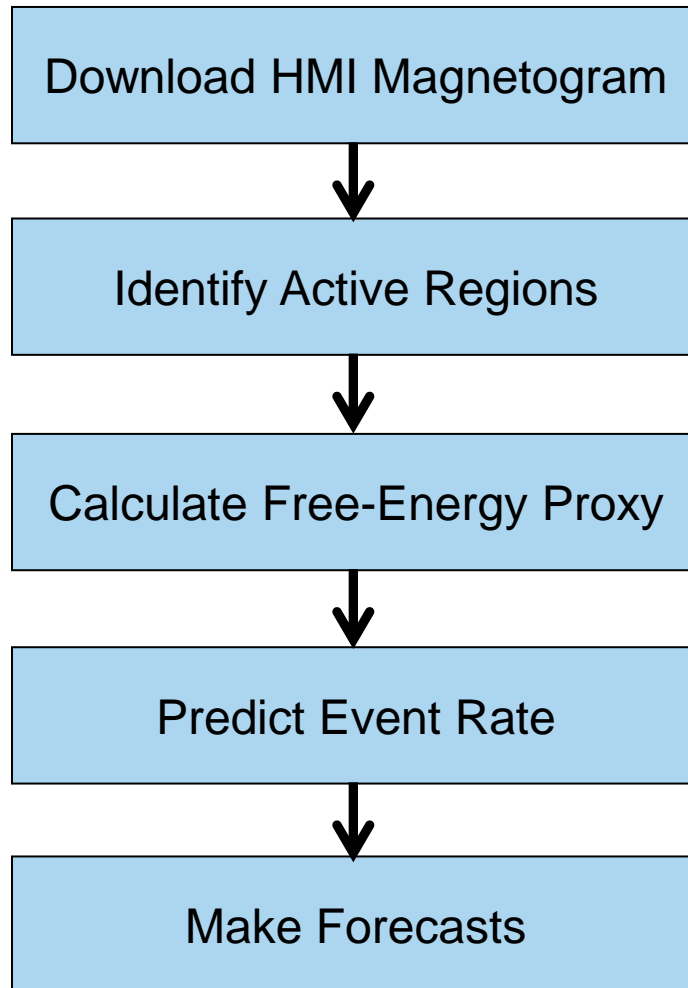
Percent Correct	$PC = (YY + NN) / (YY + YN + NY + YY)$
Probability of Detection	$POD = YY / (YY + NY)$
False Alarm Rate	$FAR = YN / (YY + YN)$
Heidke Skill Score	$HSS = 2 * (YY * NN - YN * NY) / [(YY + NY) * (NY + NN) + (YY + YN) * (YN + NN)]$
True Skill Score	$TSS = (YY * NN - NY * YN) / ((YY + NY) * (YN + NN))$

- Only 5% of the active regions produce a major flare in the next 24 hours, so Percent Correct Forecasts, will be high but misleading
- Probability of Detection is important, for big events did you forecast it. This is important.
- But if event rates are 50% chance per a day, for several days, to have a high probability of detection, you will have a higher false alarm rate.
- It is a matter of tradeoffs.

2. Skill Metrics Significance of Upgrade

Forecast Method	YY	YN	NY	NN	PC(%)	POD	FAR	HSS	TSS
McIntosh/NOAA	259	638	631	18476	93.7	0.29	0.71	0.26	0.26
Free-Energy Proxy Present MAG4	273	284	618	18830	95.5	0.31	0.50	0.35	0.47
Free-energy proxy and previous flare activity Upgraded MAG4	340	317	551	18797	95.7	0.38	0.48	0.42	0.49
Best	890	0	0	19114	100	1	0	1	1

Improvement in Metric	PC(%)	POD	FAR	HSS	TSS
McIntosh/NOAA Present MAG4	1.8±0.5 (4σ)	0.03±0.05 (0.3σ)	0.21±0.07 (3σ)	0.10±0.04 (2σ)	0.21±0.07 (3σ)
Present MAG4 Upgraded MAG4	0.2±0.2 (0.7σ)	0.08±0.03 (2σ)	0.02±0.05 (0.5σ)	0.06±0.03 (2σ)	0.03±0.05 (0.5σ)



MAG4 is completely automated, from downloading magnetograms to outputting and storing forecast products

- **2011** MAG4 installed at JSC Space Radiation Analysis Group (SRAG) as a NRT (Near-Real-Time) forecasting tool, and SRAG began pre-operations testing
- **2012** Provided NOAA web access to MAG4 NRT forecasts
- **2013** MAG4 upgraded so that it can use a combination of **free-energy proxy** and previous **flare activity, for better accuracy**
- **2013** Won the Silver Snoopy Award
- **2015** Transition from HMI line-of-sight magnetogram to vector magnetograms
- **2016** MSFC Software of the Year Award, Honorable Mention for NASA's



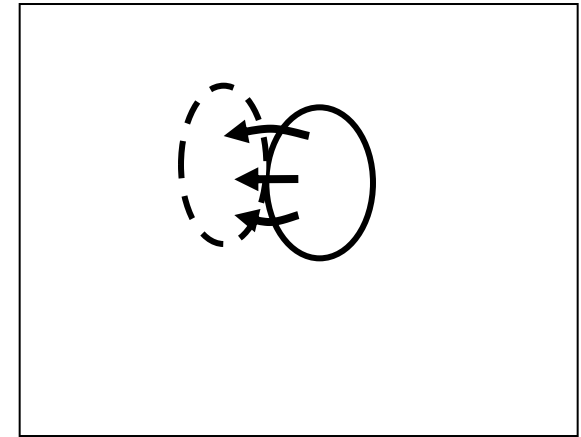
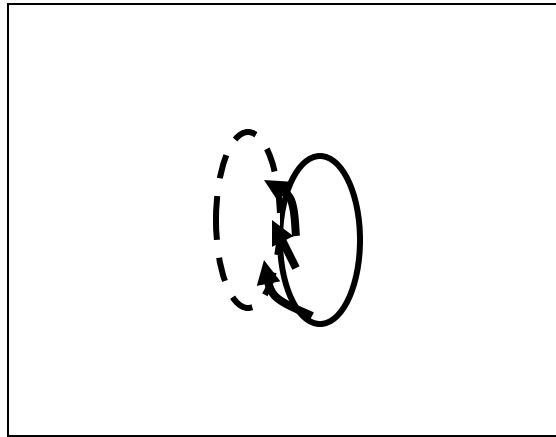
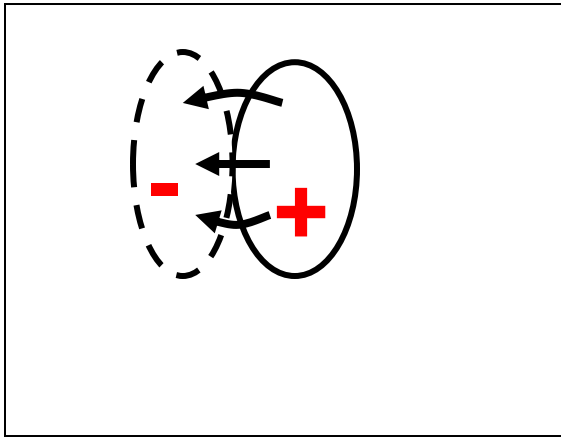
Silver Snoopy

“Employees must have significantly contributed to the human space flight program to ensure flight safety and mission success.”

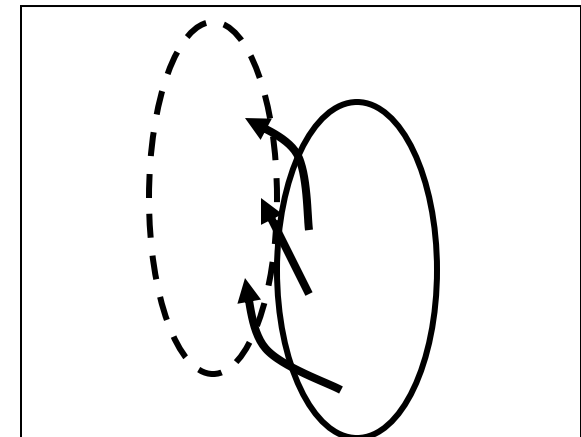
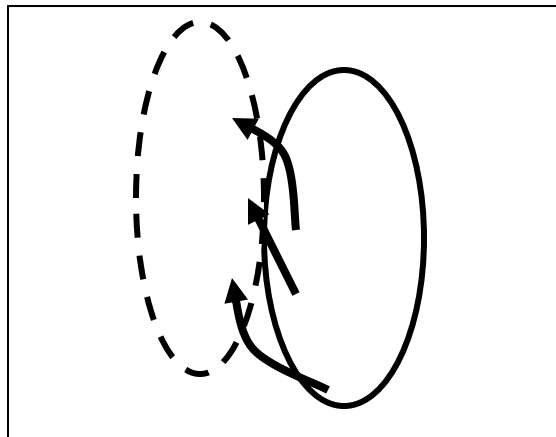
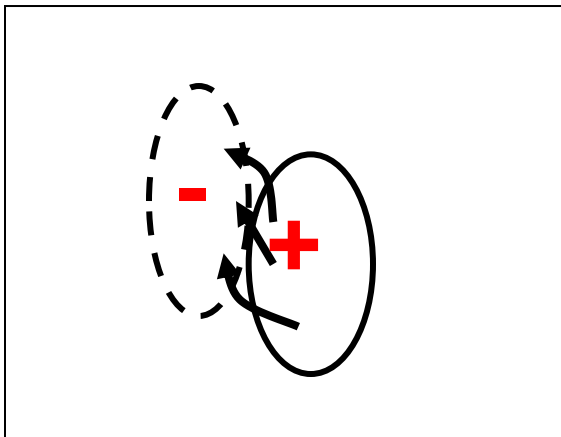
Contours Vertical Magnetic Field
Arrows Transverse Magnetic Field

Currents $\sim 10^{12}$ Amps

Less



More



Twist

Size

**Free Magnetic Energy
Or Nonpotentiality**